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HANGING VALLEYS.

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INTRODUCTION.

The following notes deal with two questions involved in the problem of glacial erosion: (1) Are hanging tributary valleys a reliable indication of glacial erosion of the main valley? (2) May not hanging tributary valleys result from glacial widening of the main valley, instead of from glacial deepening? No attempt at an exhaustive treatment of the subject of glacial erosion is made, certain phases of the problem alone being considered.

In this discussion I wish to exclude from consideration those types of hanging valleys which are not definitely related to a main stream and its tributaries; as, for example, the valleys left hanging above the beach level by the rapid encroachment of the ocean waves on the chalk shores of southeast England and northwest France; or the valleys in block mountains or block plateaus of the southwestern United States, raised above the level of adjacent plains by recent up-faulting of the blocks from which the streams flow. Let us deal only with that large class of hanging valleys found in well-defined drainage basins where the tributary streams enter the main valley at points well up on the valley sides, the tributary waters cascading abruptly downward to the main stream below. We may first enquire whether, and under what conditions, the occurrence of such hanging valleys proves that the main valley has suffered glacial erosion. If we conclude that hanging valleys sometimes or always prove glacial

erosion, it will then be pertinent to enquire whether such erosion has resulted in a mere widening of the main valley, or whether significant glacial deepening must be inferred.

THE ORIGIN OF HANGING VALLEYS.

It has frequently been urged that hanging tributary valleys might be normally produced when the main stream deepens its valley so rapidly that the weaker branches cannot keep pace with its rapid downcutting. It has also been pointed out that the conditions necessary for the production of this type of hanging valley exist only during the youth of the main stream; that period of its life history when alone it is capable of deepening its valley rapidly. I do not believe, however, that it is sufficiently appreciated how very exceptional are hanging valleys of this type. In the first place, the youth of a main stream is a period of relatively short duration. Youth is quickly passed, and the vastly longer periods of maturity and old age are entered upon. If a land mass is uplifted slowly, the stage of youth may be elided, the cycle beginning with mature valleys. The same is true in the case of more rapid elevation of weak strata. With youth elided, the possibility of hanging valleys disappears. Furthermore, there is evidence that very early in youth, if not from the beginning of stream development, tributary streams normally cut down to accordant levels with their main trunk. We should expect, then, that the chances of finding hanging tributary valleys due to the youthful overdeepening of main streams, would be very small, except in special localities which have just experienced recent and rapid uplift.

Even in regions of very recent uplift the chances of finding hanging valleys due to the rapid deepening of the main stream are smaller than might at first seem to be the case. The lower course of the main stream is first entrenched, and the effect of the revival of erosion is transmitted up the main stream and up the tributaries. When the midstream tributaries have received news of the revival, and have been left hanging above the main stream, the downstream tributaries will have adjusted themselves to the new conditions; or the falls produced by the hanging effect will have migrated up the tributaries some distance so that they will no longer be typical hanging valleys. Only in certain parts of the rejuvenating drainage system could we expect to find hanging valleys of the type here discussed.

If an uplift be accompanied by very pronounced tilting, in such a direction that the main stream is accelerated throughout its course, while the tributaries on either side are not so effected, hanging

valleys might be produced simultaneously along the entire length of the main stream. If the tilt were at an oblique angle to the course of the main stream, the main stream and the tributaries on one side would be accelerated, while the tributaries on the other side would be retarded. Hanging valleys along one side of the main stream would result. There is a greater chance of oblique tilting than of tilting exactly in the direction of the main stream's course. And since the peculiar feature of hanging valleys along one side only of a stream has not been reported, it is reasonable to suppose that hanging valleys due to the acceleration of the main stream by tilting are of rare occurrence.

I have elsewhere reported the local occurrence of what may be termed hanging valleys produced by the rapid entrenching of a main stream after capture.* When a drainage system is maturely adjusted in all its parts, the sudden introduction of an additional volume of water by capture may cause the deepening of the course along which the captured waters flow; while tributaries to that course are temporarily left in a hanging position. In the case of the capture of the Upper Chattahoochee by the Savannah River, even small tributaries have adjusted themselves to the new conditions; and it is only the very smallest branches that have failed to cut down to the new levels of the main stream. Even they have worn their falls back a short distance into the main valley wall, and no one familiar with their relations and with the hanging valleys characteristic of glaciated regions, would for a moment confuse the two. Bowman has reported the occurrence of hanging valleys due to normal stream erosion in the eastern Andes, where both the distribution and the very existence of the hanging valleys depend on an unusually favourable combination of rapid, recent, and extensive uplift, and deep dissection in rocks having strong and sudden alternations of hard and soft belts. In comparing the hanging valleys of the Andes with those of glaciated regions, he writes: "No one should misinterpret these two kinds of valleys merely because they have this in common, that they are hanging with respect to the master stream. In the assemblage of detailed characters no other likeness between the two types is discernible."† Hanging valleys of any size due to normal stream erosion are of rare occurrence, and may be recognized by their associated features.

So rare, indeed, is the theoretical probability of finding hanging valleys due to normal stream erosion, that we should be greatly sur-

* Drainage modifications in the Tallulah District, Georgia. *Proc. Bost. Soc. Nat. Hist.*, 33, 211-248, 1907.

† Unpublished manuscript.

prised were they reported in large numbers from regions where streams alone were the principal erosive agents. That they have not been so reported is certain. That they are not common features in such regions it is reasonable to conclude; for hanging valleys have been much discussed and described in late years; and if they were abundant in non-glaciated regions, surely those who do not believe in the efficacy of glacial erosion would not continue to make the mistake of citing as examples of stream-produced hanging valleys those which occur in glaciated districts. That they do not make an effective appeal to the evidence of hanging valleys in non-glaciated regions must be because hanging valleys are rare in such regions.

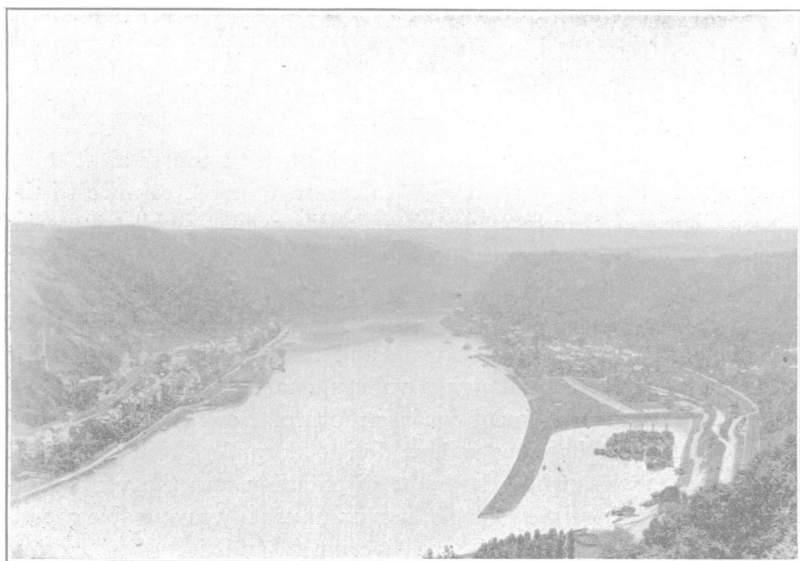


FIG. 1—GORGE OF THE RHINE AT ST. GOAR.

I have made some search for hanging tributary valleys in regions where the possibility of glacial origin could be safely eliminated. The result has been to impress upon me a fuller realization of the remarkable ease with which even small and insignificant tributaries maintain accordant junctions with the down-cutting main streams into which they empty. In a stream so young and vigorous as the Colorado River in its cañon, small tributary cañons which seldom have water in them open into the main cañon essentially at grade: a feature remarked upon by other observers. Even in the western edge of the Uinkaret plateau block, so recently uplifted by renewed movement along part of the Hurricane fault that the face of the

scarp has been but little modified, a short wet-weather ravine just south of the Virgin River, carrying water only after heavy rains, has entrenched itself until it now debouches on the lower block at grade.

The gorge of the Rhine through the upland peneplain of western Germany is a most favourable place for the occurrence of hanging valleys, if such valleys are at all characteristic of rejuvenated streams. The Rhine is a large trunk stream, joined by many tributaries on its way through the uplands. Somewhat depressed below the remarkably even surface of the uplands is a broad, shallow valley, so faintly marked in places as to be almost imperceptible, but floored with river gravels and silts. Into the bottom of this

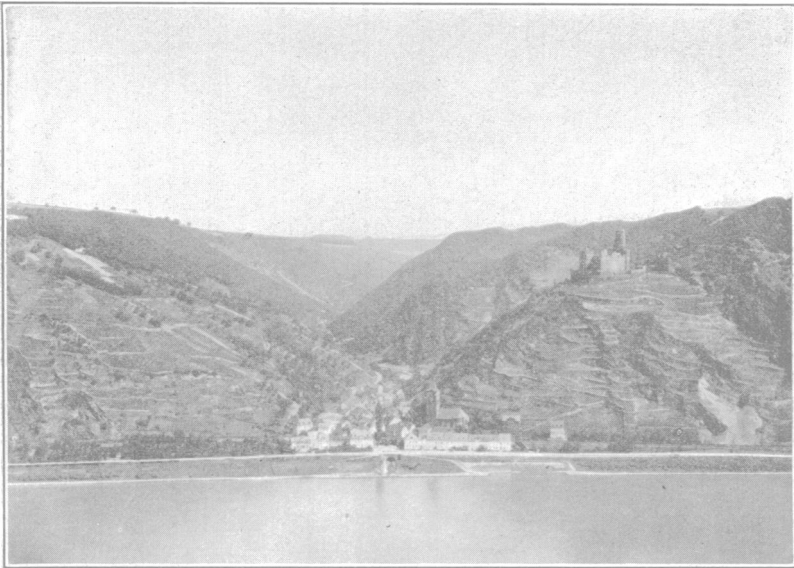


FIG. 2—JUNCTION OF WELLMICHER BACH WITH THE RHINE.

older valley the present gorge of the Rhine is sharply entrenched. Figure 1 shows the even skyline of the gently rolling uplands, a portion of the old valley floor on the upland at the right, and the gorge at St. Goar. The youthful character of the present Rhine is apparent. As a rule the river occupies nearly all of the bottom of the gorge. The walls are so steep that it is difficult to ascend them, except at certain favourable localities. On these difficultly accessible slopes stand the ruins of the ancient castles, which from commanding points dominate the river. The northern and eastern sides of the gorge, because of their good exposure to the sun's rays, have been utilized for vineyards, which produce some of the most highly prized

white wines in the world. The great value of these vineyards and the steepness of the gorge walls are both shown by the intricate series of terraces constructed to keep the soil from descending into the river. The sides of the gorge are in places traversed by a network of stone walls and arches which are carefully preserved. That the river is not yet completely graded is shown by the swift current and occasional rapids which render inexpedient the construction of piers at a few of the towns, and require landings to be made in small boats.

Into a large and vigorous main stream of such youthful characteristics, cut in rock so resistant that the gorge walls rise boldly in

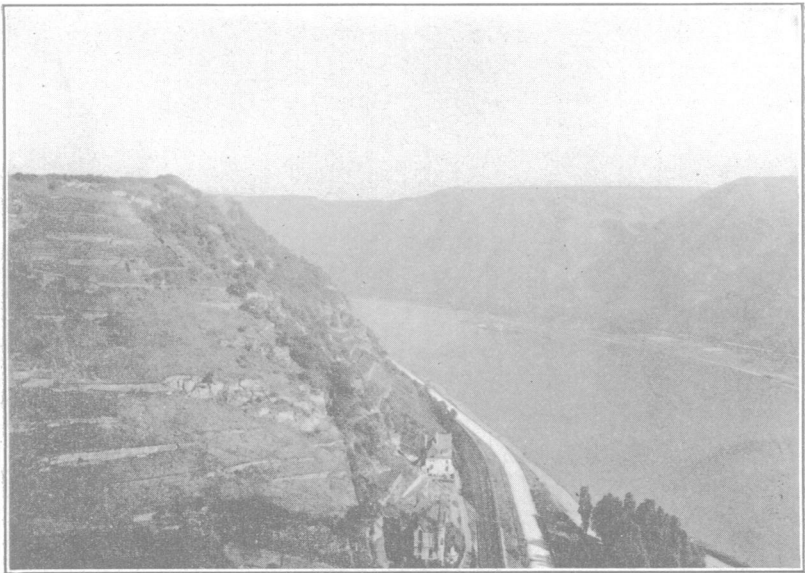


FIG. 3—GORGE OF THE RHINE BELOW ST. GOAR.

steep slopes, how do the tributary streams enter? Have they been able to keep pace with the downcutting of the main stream? Or do they possess hanging valleys? Figure 2 is a typical view of the junction of a small tributary stream with the main river. It shows the mouth of Wellmicher Bach at the town of Wellmich; the latter being located at this point partly because the accordant floor of the side valley affords a favorable space for the growth of the town. The steepness of the valley walls is suggested by the terraced vineyards.

Wellmicher Bach is a small stream, heading about five miles back in the uplands; yet it enters the Rhine with an accordant junction,

and not from a hanging valley. In the foreground of Figure 3 is seen a portion of the northwestern side of the Grindelbachthal, a tributary valley about five miles in length, which also enters the Rhine at grade. Opposite Wellmich is a ravine perhaps a mile long; and even this small ravine has an accordant junction with the main gorge. That the portion of the Rhine into which these streams empty is characteristically youthful is shown by Figure 3. These examples are typical of the relations existing between the Rhine and its tributaries throughout the gorge. The gradients of the shorter and weaker tributaries may be relatively steep. Occasional small branches may possibly be found which are sufficiently oversteepened near their mouths to be called hanging valleys in a broad sense of the term. But it is unquestionably true that even small and weak tributaries of the Rhine enter the main gorge at accordant levels, and that typical hanging valleys are absent.

It would seem that a correct answer to the first of the two questions here dealt with must be to the following effect; Hanging tributary valleys may be produced independently of glacial erosion; but hanging valleys of this type are of rare occurrence. Hence the abundant examples of hanging valleys found in glaciated regions must be in some manner related to the process of glaciation. The frequent occurrence of hanging tributary valleys in glaciated districts, and their rarity in non-glaciated districts, is a most significant relation, and one which those who doubt the glacial origin of these valleys have never explained. To say that these valleys may have been produced in some peculiar manner as yet unknown to us is not permissible. The science of physiography has reached a point where the appeal to ignorance will no longer carry much weight. That glaciers must produce hanging tributary valleys, providing they are capable of eroding their channels, has been repeatedly shown. That hanging tributary valleys are abundant in glaciated regions and not elsewhere, affords a presumption in favor of glacial erosion so strong that a constructive argument to account for this peculiar relation, instead of an appeal to ignorance, may reasonably be asked of one who proposes to reject the theory of ice erosion.

GLACIAL DEEPENING VS. GLACIAL WIDENING.

Granting that hanging tributary valleys are generally to be regarded as an indication of glacial erosion, I wish next to consider whether "over-deepening" of the main valley is to be inferred when the tributary valleys have a hanging position; or whether mere

widening of the main valley may not account for all the phenomena observed.

It has been suggested that where tributary streams enter the main stream at grade, glacial widening of the main valley alone may cause the tributaries to have hanging valleys, as shown in Figure 4. It is clear from the figure that such an origin for hanging valleys is possible, whenever the conditions implied in the figure are fulfilled. It

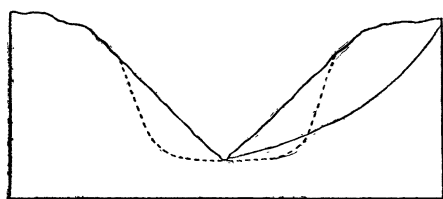


FIG. 4.

should be noted that the figure considers only such tributaries as are short and very steep. In considering hanging valleys, however, we do not deal with steep ravine notches in the valley walls, but with well-formed tributary valleys

several miles in length. Figure 5 represents an ideal profile of a side stream 2 or 3 miles in length and of rather marked gradient, entering the cross-section of a very steep-sided main valley (slope of sides 45°). The broken lines show the condition after glacial widening of such a valley, without glacial deepening.

It will appear from Figure 5 that where tributary streams are long enough and mature enough to have a gentle gradient, the opportunity for the development of hanging valleys by widening alone is very slight. The rock bottom of a glacial trough is not characteristically



FIG. 5.

flat, but gently rounded with angle of slope increasing toward the sides. It is probable that the slope of the trough floor toward its median line is in most cases greater than the gradient of tributary streams of any length, so that the lower portion of the tributary stream profile would for the most part lie below the curve of the trough bottom (see Figure 5). For this reason it is difficult to see

how glacial widening alone could possibly cause a normally graded tributary stream, several miles in length, to hang noticeably above the main stream. On theoretical grounds, therefore, we are led to conclude that **glacial over-deepening** is a prominent factor in the production of hanging valleys.

It is possible, by careful fieldwork, to test the validity of the above conclusion. I have made an attempt to do this, on a small scale, and the results are given below. Before considering these results, it is desirable to call attention to certain points which must be kept in mind when making an attempt of this kind.

Let us imagine a tributary stream, AB, Fig. 6, emptying into a glaciated main valley WXY, at the point B. Let BC represent the former continuation of AB into the preglacial main valley WCY. The actual amount of glacial over-deepening is then CX. But inas-

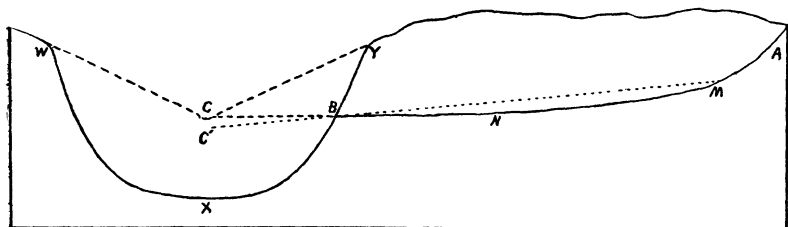


FIG. 6.

much as WCY and BC are preglacial features, totally destroyed by glaciation, it is manifest that we cannot determine the value of CX with absolute accuracy. The whole question of determining the amount of glacial overdeepening, CX, depends on our ability to restore BC correctly.

It is generally true that a stream decreases in gradient toward its mouth. That is, the profile of equilibrium is a curve steepest in its upper part, and approaching horizontality in its lower part. AM is steeper than MN, MN steeper than NB, and NB steeper than BC. On this basis we could reconstruct BC on a somewhat gentler slope than the lower portion of the stream still remaining, and so arrive at a fairly close approximation to the value CX. The danger in this method lies in the possibility that AB is not a well-graded stream, but has very different slopes in different parts of its course. NB might be an unusually flat part of the profile AC, so that BC was really steeper than NB, instead of less steep, as would be the case in a well-graded stream. The effect would be to make CX greater than it should be, or to exaggerate the amount of glacial over-deepening. The shorter and the younger the tributary stream, the

greater is the danger of falling into this error. It is manifestly important to examine a greater portion of the tributary valley than simply NB.

In order to be on the safe side, we may omit all consideration of the normal variations in the gradient of the valley downstream from some point near its headward portion, as M, Figure 6, and consider the dotted line MB as the average gradient of the tributary valley, and the line BC' as the former continuation of this valley. As will appear from the figure, this method will be pretty sure to lead to an underestimate of the extent of glacial overdeepening: there will be little or no chance for an overestimate, except under the improbable conditions noted in the next paragraph. In case the tributary valley has a very uniform slope from near its head to its mouth, the lines MNBC and MBC' coincide, and the quantity CC' becomes zero.

Three objections might be urged against this method. It might be said that in preglacial time the line BC' did not continue as projected, but took a sharp bend down to X; and that if we admit this possibility, there has been no glacial deepening after all. This, in effect, would be to argue the existence, in preglacial time, of an abundance of hanging valleys due to normal stream erosion. For it is plain that by this interpretation AB is a hanging valley, or a hanging valley but slightly cut back in its lower course. That numerous hanging valleys due to normal stream erosion are extremely improbable has already been shown. Furthermore, the advocate of such an interpretation would have to explain the remarkable abundance of preglacial hanging valleys in regions later to be glaciated, and their absence elsewhere. This last statement applies with equal force to the suggestion that preglacial entrenching of the main stream may have caused each tributary stream to become oversteepened in its lower course enough to give, not an abrupt drop downward to X, but a gradually increasing slope (a profile convex upward) leading down to X. While such oversteepening might occur locally, in the case of weak tributaries, it cannot be admitted as a characteristic feature of preglacial topography, for reasons discussed in the first part of this paper.

In the second place, it might be urged that the centre of the preglacial valley was not in line with the centre of the present glacial trough, but well to one side of it. If the trough were very broad and flat bottomed, as in Figure 7, it is evident that the method here proposed might lead one to calculate glacial overdeepening amounting to CX whereas there had been no overdeepening at all, but only widening. It should be noted, however, that while this objection might be

urged, under the special conditions represented in Figure 7, against conclusions derived from the study of a single hanging tributary valley, the objection is ruled out when hanging valleys occur on both sides of the main trough. This may be seen by imagining another hanging valley DE, similar to NB, to enter the opposite side of the

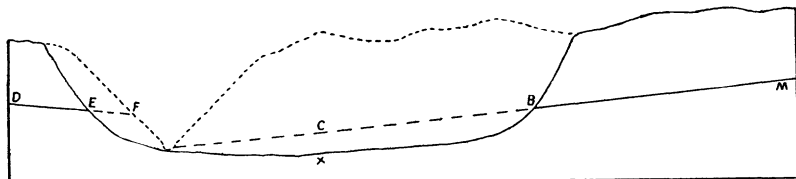


FIG. 7.

glacial trough. Its prolongation, EF, shows that it would be a hanging valley due to normal stream erosion, an improbability already fully considered. It may be further noted that in most of the cases observed by the writer, the prolongation of the tributary valley would not touch the floor of the main trough even at the farther side of the trough, but would strike some distance up on the opposite wall. A quick qualitative way to determine this point is as follows: If from no point on the floor of the main valley the floor of the tributary valley is visible; or if from a point some distance back in the hanging valley no part of the main valley floor is visible, there has been glacial overdeepening of the main valley. It should be noted that the converse propositions are by no means necessarily true. A valley deepened by glacial erosion might be so widened that the farther side of the main valley floor might be seen from well back within the hanging valley; or the floor of the hanging valley might be visible from the farther side of the main valley floor.

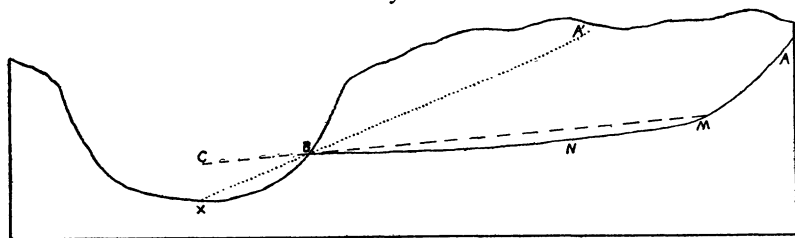


FIG. 8.

A third objection to the method here employed for determining glacial overdeepening might be to the effect that glaciation had so changed the tributary valley that it no longer had so steep a slope as in preglacial times. For example in Figure 8, whereas we calculate the glacial overdeepening of the main valley as CX on the basis of an

average slope of MBC in the tributary valley, it might be urged that the preglacial tributary valley had a slope A'BX, and that there had accordingly been no glacial deepening of the main valley, but simple valley widening. This is an objection which can only be urged by a believer in profound glacial erosion. For since the present tributary valley has the curve ANB, glacial erosion must have deepened this valley by the amount A'N. Postglacial stream erosion could not be appealed to, for such erosion has not been able even to reduce the hanging effect at B. Furthermore, the tributary valleys often show glacial markings and glacial deposits over their walls and floors, but little effected by postglacial erosion. Small notches are sometimes found in the lips and floors of glaciated hanging valleys, and show that postglacial erosion has been very limited in amount. As shown in Figure 8, the lip, B, of the hanging valley is a fulcrum point, nearer to the center of the main valley than to the headward portion of the hanging valley. It follows, that in order to get rid of a moderate amount of glacial deepening in the main valley, we must admit an enormously greater amount of glacial deepening in the hanging valley; and must further suppose that this glacial deepening was restricted to the upper portion of the tributary valley, in order that the elevation of B should not be lowered; and that the main valley was glacially *widened* to give the typical hanging effect. That such a special combination of circumstances was an important factor in producing the numerous hanging valleys of glaciated regions must be doubted. It is quite possible that relatively more effective erosion in the upper parts of some tributary valleys, especially during the waning of the glacial epoch, may have resulted in decreasing the average slope of the tributary valleys, and that the quantity of overdeepening figured on the basis of the method here described might be overestimated in such cases. But it appears from Figure 8 that a considerable amount of overdeepening of the tributary under these conditions would introduce a relatively small error into the calculation of overdeepening in the main valley. In tributary valleys a number of miles in length, the possibility of overestimate from this source must be very small. It should be possible in some cases, by examining the relations of the hanging valley to its own small branches, to determine with approximate accuracy the amount of overdeepening in its several parts.

While a considerable overdeepening of the headward portion of a hanging tributary valley has a relatively small effect on the calculation of the glacial overdeepening of the main valley, any overdeepening of the lower course of a hanging valley introduces an

appreciable error into such a calculation. If the mouth of a hanging valley has been deepened 200 feet below its preglacial level, the calculated overdeepening of the main valley, C'X in Figure 6, will be about 200 feet too small. I am convinced that wherever the mouth of a hanging valley has been materially altered to the typical glacial trough form, we must infer a greater or less amount of glacial deepening at that point, and must take it into account when estimating the overdeepening of the main valley. Furthermore, the main valley trough is apt to be floored with stream deposits or lake waters, or both; and the true depth of the trough thus concealed.

It is evident, from all that has been said, that the total amount of glacial overdeepening, as determined from a study of the relations of the main and tributary valleys, is equal to (1) the definitely calculated amount C'X, (Figure 6) plus (2) the indeterminate amount CC' due to the too great slope figured for the prolonged lower course BC', of the tributary stream, plus (3) the depth of glacial erosion in the lower course of the tributary valley, plus (4) the depth of the water or waste on the floor of the main valley, minus (5) an uncertain but probably negligible amount due to a decrease in slope of the tributary valley resulting from excessive glacial erosion in the headward portion of the valley. It need hardly be added that in making these calculations, the observer must sharply discriminate between the preglacial elements in the topography, the slopes due to glacial erosion, and the narrow notches cut by postglacial erosion in the lips and floors of glaciated valleys.

GLACIATED VALLEYS IN EUROPE.

With the above principles in mind I have examined some of the hanging valleys in the glaciated districts of France, Switzerland, northern Italy, the English Lake District, and the Highlands of Scotland. It would be more accurate to say that some of the valleys were examined with only some of the principles in mind; for the details above discussed were in part elaborated during the progress of field observation and study. It was found that properly to evaluate all of the factors in the problem for most of the hanging valleys observed, would require more elaborate field surveying than I was able to give. The amount of glacial overdeepening of the main valley had often to be roughly estimated; but as to the fact of appreciable overdeepening in most cases, I could entertain no doubt. The following three examples of overdeepened main valleys will serve to illustrate the principles discussed in this paper, which will, I hope, be

further elaborated and tested by some who can give more time to the problem than it was possible for me to give.

The valley of the Upper Engadine in Switzerland, extending northeastward from Maloggia Pass, offers abundant evidence of its former occupation by ice. The "trough" form is not so symmetrical as in many glaciated valleys, but is distinctly present. A series of small lakes occupies the bottom of the trough between Maloggia and St. Moritz, and while these lakes have been referred to as typical illustrations of the lakes sometimes associated with river capture, there is reason to believe that they are in no way related to the drainage modifications which have undoubtedly occurred near Maloggia Pass, but are to be classed with the lakes found so abundantly in glacial troughs in all regions of Alpine glaciation. Three of these lakes, the Silser See, the Silvaplaner See, and the See von Campfer, formerly constituted a single body of water. The two former have been separated by the growth of the Sils delta, deposited mainly by a stream draining the hanging Val Fex. The Silvaplaner See and the See von Campfer have been separated by the all but complete junction of the Silvaplana and Surley deltas, built out from hanging valleys on opposite sides of the main trough. The Silser See is in the process of being divided into two parts by the Isola delta, which is being deposited by a stream issuing from the hanging Val Fedoz. We thus find in the Upper Engadine three different stages of a process carried to completion in the oft-cited Interlaken case. The physiographic relations of the great Shantung peninsula, in China, are here repeated on a miniature scale, small rocky islands, formerly out in the midst of the lake, being now tied to the main shore by the growth of three of the deltas. Every delta has determined the location of a village.

The Val Fedoz (Figure 9) is a fairly simple type of the hanging valleys of this region. The stream which drains it heads at the foot of the Fedoz glacier a few miles to the south, and flows northward with fairly uniform slope until near the hanging junction with the main trough. Here a narrow postglacial gorge has been cut, in which the stream cascades down through the lip of its hanging valley to the level of the Silser See, into which it is building the Isola delta. A zigzag road leads from Isola village up into the hanging valley. Standing on the opposite side of the main trough, it is impossible to see the floor of the Val Fedoz, so great has been the deepening of the main trough. That the Val Fedoz has itself been profoundly glaciated is evident from its beautiful glacial trough form.

The Swiss contour maps give the surface level of the Silser See

as 1,796 meters; the lip of the Val Fedoz is about 150 meters higher; for 3,800 meters south of here the valley has a rather uniform slope up to the 2,070-meter contour line. If we plot these points to natural scale, and project the slope of the Val Fedoz out to the central area of the main valley, the projected line falls about 120 meters above the level of the Silser See. There is a strong probability that the Val Fedoz has been considerably deepened throughout its length in the course of the profound glaciation which it has suffered. The total amount of glacial overdeepening of the main valley, then, is 400 feet + 200 feet, the depth of the Silser See + the depth of the sediments accumulated in the bottom of the lake, + the amount of glacial deepening of the Val Fedoz,—a few feet correction to be

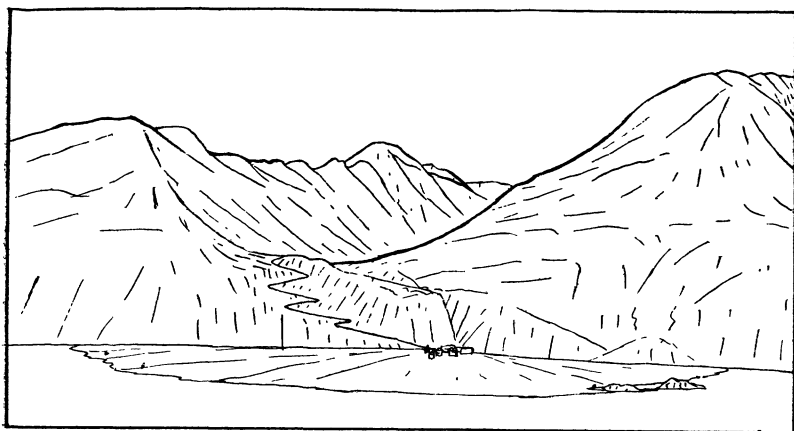


FIG. 9—HANGING VAL FEDOZ, AND THE ISOLA DELTA. (DRAWN FROM PHOTOGRAPH.)

applied if the southern end (head) of Val Fedoz has been deepened much more than the northern end. A total overdeepening of 700 feet in the main valley of the Upper Engadine due to glacial erosion, is a conservative estimate.

The remarkable hanging valleys along the Ticino above Lake Maggiore in Italian Switzerland have been described by Davis.* That the main trough of the Ticino has been profoundly overdeepened by glacial erosion is the conviction which grows upon one who endeavors to analyze the topography and to reconstruct the pre-glacial conditions. I can add nothing to the appreciative description of these valleys by the above cited author, except a brief account of my own attempt to get a rough quantitative statement for the amount of overdeepening in the vicinity of Biasca. After an ineffectual

* "Glacial Erosion in the Valley of the Ticino," *Appalachia*, 9, 136-156, 1900.

attempt to ascend the precipitous southwest wall of the main trough, high enough to look into the hanging Val Nadro, I climbed up into the lower portion of the Val d'Ambra. In this region there is distinctly shown a younger trough (Figure 10) within an older trough, both of which are probably due to glaciation. The Ambra, a stream four miles or more long, flows in a postglacial trench cut in the bottom of a glaciated tributary valley, then down a similar trench in the steeper slope of the outer trough, and finally in a sharply cut notch down the very steep side of the inner, younger trough, to the Ticino River.

Even if we reckon the overdeepening from the edge of the inner

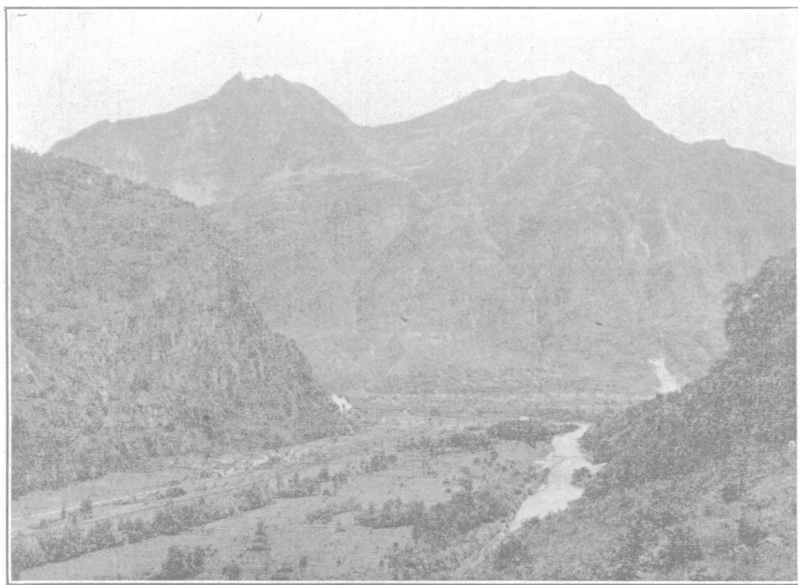


FIG. 10—VALLEY OF THE TICINO, NEAR BIASCA.

trough alone, we find evidence of significant glacial erosion. The elevation of the main Ticino Valley in this vicinity is about 300 meters. The elevation of the rim of the inner trough, from which the Ambra drops abruptly to the level of the Ticino, is about 510 meters. 2,300 meters to the southwest the Ambra is about at the 870-meter contour line (exact position of contour line difficult to locate). On the basis of these figures, which relate to the post-glacial gorge of the Ambra in the portion of its course above the rim of the inner trough, the main valley has been overdeepened 330 feet + the depth of the deposits on the floor of the trough + the

glacial deepening of the Ambra Valley + the postglacial trenching of the Ambra River. Judging by the "shoulders" (above the postglacial trench of the Ambra) on which Matra and other small villages are located, the floor of the glacial Val d'Ambra proper has an elevation of something like 900 meters. This corresponds roughly with a prominent shoulder along the main trough on which numerous villages are picturesquely situated high above the Ticino. Allowing for a steep gradient in the glaciated tributary, the total overdeepening of the outer and inner troughs combined, can scarcely be less than 1,200 feet + the depth of the deposits on the bottom of the inner trough + the amount of glacial overdeepening of the Val d'Ambra.

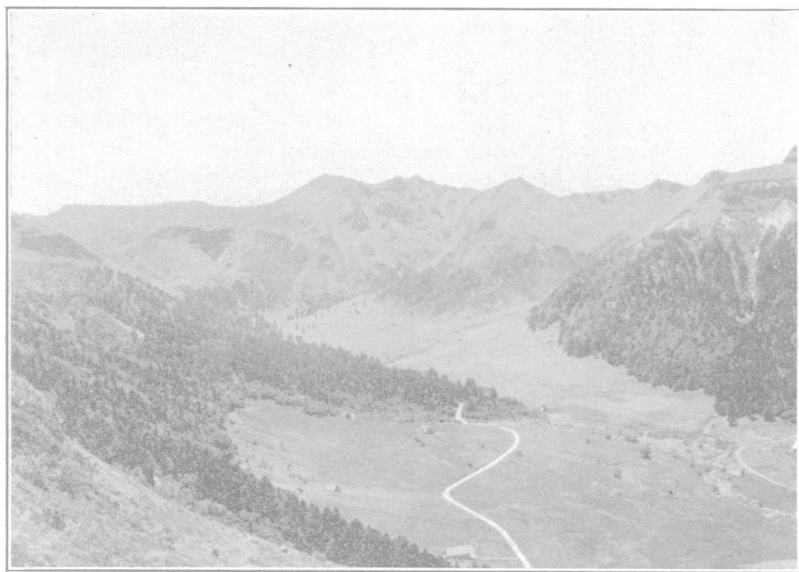


FIG. 11—HEAD OF MONT DORE VALLEY, CENTRAL FRANCE.

Above the upland peneplain of central France, generally called the Central Plateau, rises the dissected volcano of Mont Dore. One of the radial consequent valleys which resulted from the dissection of the volcano is drained by the northward-flowing Dordogne River, and in this valley is located the picturesque little town of Mont Dore, famous for its mineral springs and baths. The Mont Dore valley, as we may call it, has been profoundly modified by Alpine glaciation. The southern part of the valley (Figure 11) is open and its sides dissected into the sharp angular peaks so frequently found in the gathering grounds of glaciers. Toward the north the valley narrows and assumes the remarkably smooth trough-like form common to well

developed glacial channels (Figure 12). Just south of Mont Dore a small stream heading a little over a mile to the southeast of its junction with the Dordogne, falls over a hard layer of volcanic rock into the Mont Dore valley, forming La Grande Cascade. It is a small hanging tributary entering the main Mont Dore trough with a strikingly discordant junction.

The floor of the Mont Dore trough has an elevation of 1,050 meters. A point near the head of one branch of the tributary valley has an elevation of 1,414 meters. No figure is given for the crest of the cataract, but judging by other data for nearby points the crest of the cataract, or the mouth of the hanging valleys, has an elevation

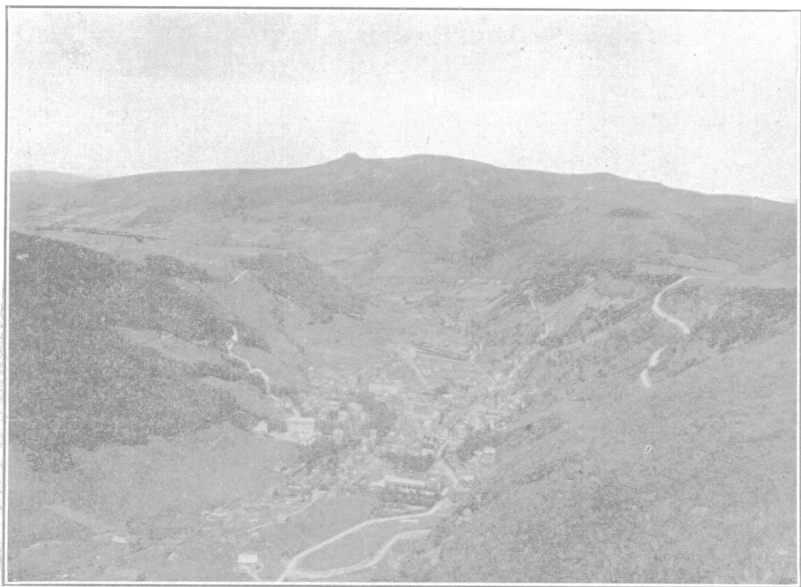


FIG. 12—GLACIAL TROUGH AT MONT DORE. (PHOTO, TAKEN FROM LIP OF HANGING VALLEY.)

probably not under 1,340 meters, and certainly not under 1,300 meters. On the basis of the first figure, the directly calculated overdeepening of the main trough amounts to 740 feet. On the basis of the second figure the directly calculated overdeepening amounts to 500 feet. The hanging valley has been little if at all modified by glacial action, so there is no correction to apply for glacial overdeepening along its course. But the lower part of its remaining course is noticeably of a more gentle gradient than the part next upstream, so it seems possible that some correction must be made on account of a calculated average slope of too great an inclina-

tion. On the other hand, it is possible that the gentle gradient at this point is due to the hard rock layer over which the stream is flowing, and that the former continuation of the tributary was not so flat. Accordingly, the overdeepening of the Mont Dore valley, due to glacial erosion, amounts to 740 feet (or 500 feet) + the depth of deposits on the floor of the valley + (?) an uncertain but perhaps significant amount, correction applied for excessive gradient assumed in calculation. That the total overdeepening may amount to 900 feet is quite possible.

One value of the method above outlined lies in the fact that it directs attention specifically to the several variable elements involved in the calculation of glacial erosion, and calls for careful evaluation of each. That the method is more reliable than the projection of remnants of the V-shaped valleys above the glacial trough, where these remain, will be evident from a consideration of Figure 13.

Imagine the gorge of the Rhine near St. Goar (Figure 1), with its accordant tributary valleys (Figure 13, solid lines), to be markedly overdeepened by glacial erosion. The projections of the remnants

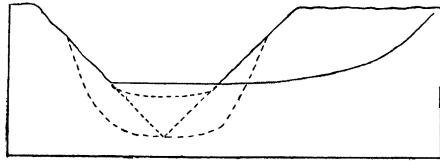


FIG. 13.

of the old valley walls touch the bottom of the glacial trough (Figure 13, dotted lines) and indicate that there has been no glacial deepening. A study of the hanging valleys would prove the fact of deepening, and gave an approximate idea as to its amount. Further objections to the reconstruction of preglacial valleys on the basis of a study of the higher slopes, are found in the variability of those slopes and in the possibility of their indeterminate modification by unusually high level glaciation.

In the European illustrations given above, careful field work would enable one to supply some or all of the unknown quantities, such as the depth of alluvial deposits on trough floors, the relative amount of glacial deepening in the upper and lower courses of hanging valleys, etc., and thus to determine within fairly narrow limits the actual amount of overdeepening due to glacial erosion of stream formed valleys.